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Improving Students' Communication Skills and Systems Thinking Ability in Circular Economy through Combination Learning Module

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Abstract

Many modern buildings are designed and constructed without considering proper methods of disassembly, reuse, recycling, or disposal after the end of their service life. Consequently, a significant amount of waste produced from building demolition is disposed of in a landfill. Although time and cost are essential factors while designing a built environment, it is also critical to ensure the implementation of circular economy practices through the systematic reuse or recycling of building materials at the later stage of its lifecycle. One of the most effective ways of increasing awareness of the circular economy principle in construction education is by educating the future construction workforce about circular economy concepts such as life cycle analysis, design for disassembly, and deconstruction strategies. However, such novel concepts are seldom integrated into the construction management curriculum which limits students' ability to understand the importance of designing and constructing buildings for easy disassembly as well as potential reuse or recycling possibilities at the end-of-life cycle. Therefore, this study aims to improve construction management (CM) students' systems thinking ability in circular economy and conceptualize their ideas about design for disassembly. To achieve this goal, the study integrated a combination learning model through a flexible combination of problem-based learning (PBL) and concept map development (CMD) activity in three CM courses including Principles of Construction, Sustainable Construction, and Sustainable Approach to Construction. Overall, 61 students participated in the pre-and post-course survey and a Wilcoxon-signed rank test is utilized to analyze the obtained data. The results of the statistical analysis indicated that students significantly improved their systems thinking ability, technical communication, and interdisciplinary communication skills. Additionally, PBL and CMD activity enhanced students' ability to conceptualize systems thinking by focusing on how the concepts and patterns in one system influence other systems and circular economy outcomes dynamically. The findings of the study contribute to the architectural, engineering, and sustainable construction body of knowledge by educating the future construction workforce about novel concepts of circular economy, design for disassembly, and deconstruction as well as developing soft skills to communicate their technical knowledge effectively.

Keywords: Circular Economy, Problem-based Learning, Concept Mapping, Systems thinking

Introduction and Background

The circular economy is associated with the concepts of recycling, reusing, reducing, and rethinking, and it is defined as designing materials for durability, reuse, remanufacturing, and recycling to keep products, components, and materials circulating in the economy [1].

Deconstruction is one of the circular economy methods for faster recovery of building products, parts, materials, and components to minimize environmental impact and maximize economic value through reuse, recycling, repair, and remanufacture [2]. For proper deconstruction of building components, buildings need to be designed for disassembly. Some of the key principles for designing the building for disassembly include: (a) proper documentation of methods and materials used for construction such that it can be utilized during deconstruction; (b) use of connections that are easy to dismantle (e.g., using screwed, nailed, and bolted connections; using modular or prefabricated structure; and reducing chemical and welding connections); (c) use homogeneous materials and reduce the use of hazardous materials; (d) design simple structure and forms that allow the standardization of dimensions and components; and (e) separation of non-recyclable, non-reusable, and non-disposal items such as mechanical, electrical, and plumbing (MEP) systems [3]. Although these circular economy approaches are one of the most advocated sustainability practices in the Architecture, Engineering, and Construction (AEC) industry, it is not yet widely practiced. Additionally, it is critical to educate the future workforce about circular economy practices to reduce embodied energy in the production of new materials by substituting recovered existing materials as a resource for construction.

Cappuyns and Stough (2016) highlighted that a lack of awareness and a lack of educational programs related to a circular economy are major barriers impeding the adoption of a circular economy in the Architecture, Engineering, and construction (AEC) industry [4]. The study highlighted that the interdisciplinary assessment project (IAP) offered at KU Leuven, Belgium helped students acquire knowledge about practical applications of circular economy and improved their soft skills to manage circular economy-based goods and services. Similarly, a higher education institution in Mexico redesigned and restructured the construction management course at an undergraduate level and highlighted the importance of integrating circular economy concepts to promote sustainable development competencies among the future workforce [5]. Additionally, the integration of circular economy concepts in an urban design and planning course helped students to understand and differentiate the relations between different subsystems and their spatial structures such that they can address challenges from a systemic perspective instead of a design process [6]. Several European universities have also explored the use of simulation and serious games as a tool to introduce circular economy and sustainable energy concepts among students [7]. Students tend to face non-trivial cognitive challenges in traditional pedagogical approaches while learning circular economy concepts due to the complex interaction of social, environmental, and economic systems in the circular economy. Although a simulation-based pedagogical approach can help students to learn about these concepts, they may not be capable to implement the circular economy concepts to solve complex problems in their profession. Hence, there is a pressing need for an innovative pedagogical approach that not only improves students' knowledge about the circular economy but also improves their ability to solve real-world problems using circular economy principles.

The problem-based learning is an unconventional mode of teaching that has been found to improve the quality of learning through the integration of open-ended complex questions. It is extensively used in AEC education as a flexible and practical approach to engaging students in complex problem-solving and critical thinking [8]. Similarly, concept map development activity is also an active learning method that evaluates students' systems thinking ability and helps students to develop metacognitive skills [9]. Pruett and Weigel (2020) implemented a concept mapping method to assess whether community-engaged fieldwork in an upper-level ecology lab course enhances sustainability knowledge among future biologists [10]. The study highlighted that those students reported a significant increase in the depth, breadth, and complexity of their knowledge. In particular, there was a 39% increase in the number of concepts in the concept map between pre-and post-experience surveys. Chang et al. (2022) conducted a bibliometric analysis and systematic review of scientific publications from 1992 to 2020 on trends, roles, and application of concept maps [11]. The study indicated that there were significant improvements in learning achievements, motivations, and collaborative learning within engineering, science, and language courses due to the use of the concept maps. However, studies have seldom evaluated the efficacy of integrating problem-based learning and concept map development methods in AEC education. Additionally, studies have also not assessed if the benefits of both pedagogical approaches can be achieved in a single combination learning module.

Therefore, this study aims to integrate circular economy concepts such as life-cycle analysis, design for disassembly, and deconstruction, among others in AEC education through a flexible combination of problem-based learning and concept map development activities. The combination learning module not only evaluated students' circular economy knowledge but also their technical and interdisciplinary communication skills, systems thinking ability, and ability to provide feedback and receive criticism, among others.

Methodology

This study utilizes a mixed-method sequential exploratory design to capture and quantify the efficacy of a combination learning model through a flexible combination of problem-based learning (PBL) and concept map development (CMD) activity. The study utilized a pre-and post-course survey to collect quantitative and qualitative data. The survey included socio-demographic questions, Likert scale questions, and open-ended questions. There are four main guiding research questions in this study: (1) What are the current skills level of students' technical communication skills, interdisciplinary communication skills, and systems thinking ability related to a circular economy?; (2) How confident are students to provide feedback, receive criticism, and communicate effectively about the circular economy after their involvement in a combination learning module (i.e., coupling of problem-based learning and concept map development activity)?; and (3) What is the degree of polarity (i.e., positive, negative, or neutral) of students towards combination learning module? This research implemented a combination learning model including problem-based learning and concept map development activity in three courses (i.e., Sustainable construction, Principles of Construction, and Sustainable approach to construction). Overall, there were 47 undergraduate students from Sustainable Construction and Principles of Construction whereas 14 graduate students participated in Sustainable Approach to Construction. All the students participated in a pre-course survey at the beginning of the class. The pre-course survey included a Likert scale and multiple-choice questions related to their current skills level in technical communication skills, interdisciplinary communication skills, and systems thinking ability and confidence to provide feedback, receive criticism, and communicate effectively about the circular economy. Additionally, the pre-course survey also collected socio-demographic data. Before students' involvement in problem-based learning and concept mapping activity, the authors introduced students to different existing concepts of circular economy in construction: (1) Life cycle assessment of building; (2) Differences between embodied carbon and operational carbon; (3) The working mechanism of linear, recycling, and circular process; (4) case-studies of upcycling and downcycling; and (5) concepts of design for disassembly and deconstruction. The authors delivered a 45-minute lecture-based module to teach these concepts which were followed by a combination learning module.

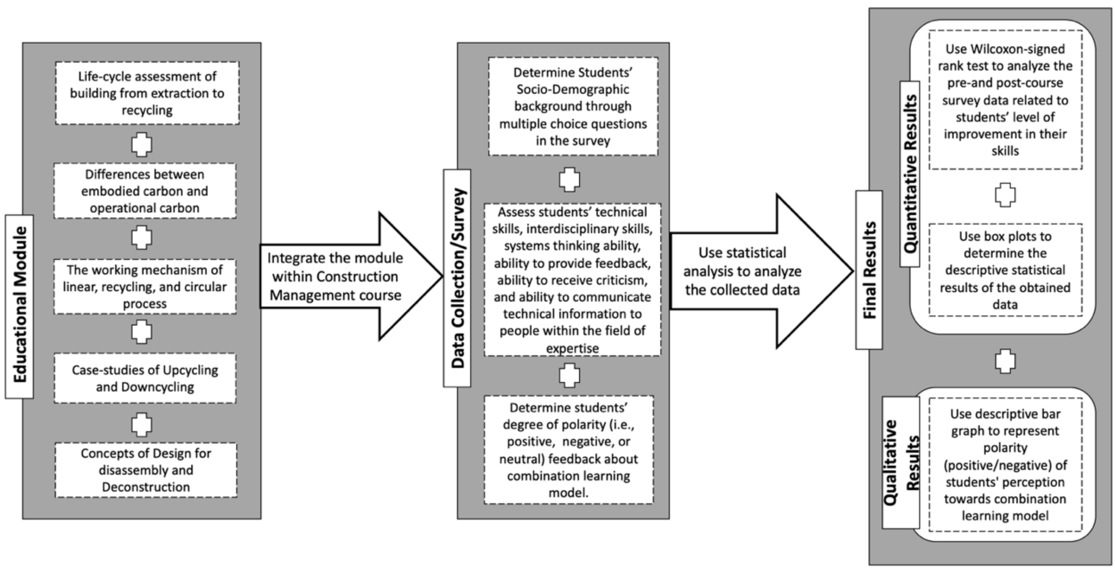

Figure 1. Research Framework

After the lecture, the authors instructed students to solve a real-world problem related to waste management problem in Florida through the adoption of the circular economy principle: "*Construction and Demolition (C&D) debris accounts for more than 25% of Florida's total municipal solid waste. The Florida Department of Environmental Protection established a recycling goal of 70% by 2018 and 75% by 2020. However, Florida's 2018 C&D recycling rate was 49%. Design for disassembly is one of the best ways to address the high consumption of resources and the low recycling rate in the construction industry. Develop a concept map to address the low recycling rate of C&D waste from building construction in Florida by integrating design for disassembly or circular economy in construction practice. Create a concept map to address the problem."* For developing the concept map students were provided with the following instructions:

- Brainstorm a list of the major terms or concepts related to the design for disassembly or circular economy.

- Sort through the list and group concepts related to one another.
- Based on these relationships, arrange the concepts on a page, leaving space for connecting lines.
- Draw lines between the concepts that you think are related.
- Write on each line the nature of the relationship between the concepts.
- Add any new concepts and relationships that will help better explain the map created.

After providing the instructions, students were divided into a group of four or five. In general, students were provided with 30 mins to discuss and create the conceptual model of a proposed solution using the CMap tool. The authors provided additional resources to improve their solution and an additional 10 mins were provided to students for finalizing the concept map. Then, the authors instructed students to choose a group representative to present the proposed solution in the concept map within 3 mins. Finally, the concept map with their proposed solution was evaluated based on the content, relationships between concepts, and organization of the concept map for assessing the quality of the concept map. After completing the presentations, students participated in the post-course survey. The post-course survey included similar questions related to improvement in skills level in technical communication skills, interdisciplinary communication skills, and systems thinking ability and confidence to provide feedback, receive criticism, and communicate effectively about the circular economy. Additionally, the post-course survey included open-ended questions related to their perception of the combination learning module (i.e., problem-based learning activity and concept map development activity) and how it has helped them to learn about circular economy. A Wilcoxon Signed-Rank analysis evaluated the obtained pre- and post-course data to determine the efficacy of the combination learning module. The pre-and post-course data assessed students' technical skills (i.e., talking with someone from within the course about the circular economy), Interdisciplinary skills (i.e., talking about technical details with someone from outside the course about the circular economy), systems thinking ability in the circular economy, ability to provide feedback to team members about the circular economy, ability to receive criticism from team members, and ability to communicate technical information related to a circular economy to people within the field of expertise. A Wilcoxon Signed-Rank test is a nonparametric test used for paired data (i.e., pre-, and post-surveys). This test is implemented if the differences between pairs of data are non-normally distributed [12]. The authors utilized SPSS to conduct the Wilcoxon analysis with the confidence interval set to 95% and the maximum desired P-value of 0.05. Furthermore, the scope of the combination learning module was graphically represented with box plots to investigate the efficacy of the pedagogical approach to support students in four different areas: (1) solve problems in other courses; (2) brainstorm ideas for real-world problems in their professional career; (3) educate peers about circular economy concepts such as deconstruction and design for disassembly; and (4) implement the circular economy principle in their professional career. Box plots are one of the most common methods for graphically analyzing the distribution of data sets [13]. The box in the box plot typically includes the interquartile range of the dataset, i.e., values between the 25^{th} and 75^{th} percentile. A dark horizontal line represents the median value in the box. A whisker or lines extending above and below the box indicate the largest and smallest observed values.

Results and Discussion

This study utilized a mixed-methods sequential explanatory design to collect and analyze both quantitative and qualitative data. This section demonstrates obtained results: (1) students' technical communication skills, interdisciplinary communication skills, and systems thinking ability; (2) students' confidence to provide feedback, receive criticism, and communicate technical information effectively to team members and people within the field of expertise; and (3) efficacy of combinational learning model (i.e., problem-based learning and concept map development activity). Figure 2 shows the overall socio-demographic information of 61 students from Sustainable Construction, Sustainable Approach to Construction, and Principles of Construction. Students from different socio-demographic backgrounds participated in the study, which included: (1) 46 Hispanic and 13 non-Hispanics; and (2) 46 white, 5 African Americans, 1 Asian, and 2 more than one race. Additionally, 90% of the students are currently working outside the university, and most of the students were found to be local students.

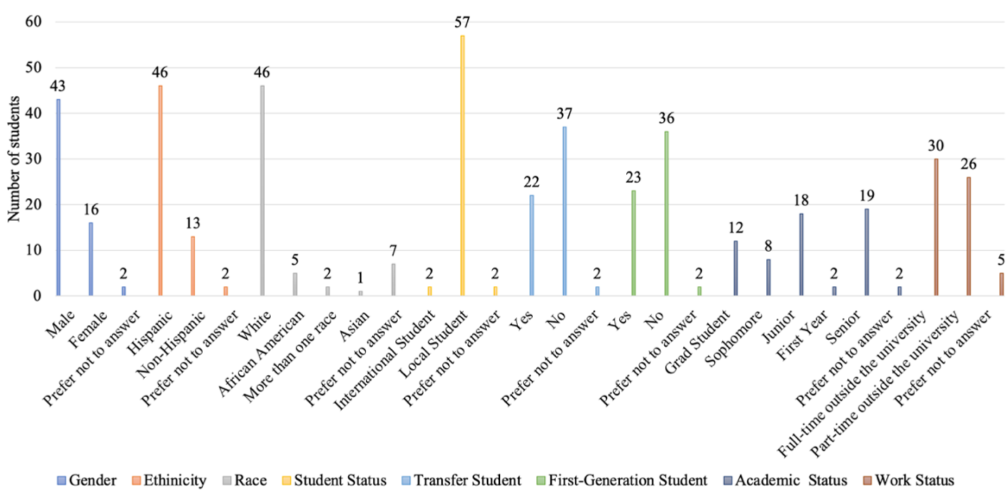

Figure 2. Students' socio-demographic background, n=61

Circular Economy Concept Map Developed by Students

The concept map development activity helped students to conceptualize their solutions and the implications of their decisions. Since this activity involved actively working on a real-world problem that impacts the environment, there was an increase in student engagement and collaboration. Students' involvement in this activity enhanced their ability to conceptualize systems thinking by focusing on how the concepts and patterns in one system influence other systems in the circular economy. During the group activity in the combination learning module, students were divided into groups of 4. Overall, 15 student groups prepared 15 different concept maps for the given problem. For instance, Figure 3 shows a sample concept map created by a student group. The concept map is non-linearly organized with concept integration and feedback loops that provide a complete picture of students' solutions. All the concept maps were evaluated based on the rubric or grading matrix developed by Valdes-Vasquez and Klotz (2011). According to the grading matrix, content, relationships, and organization are three primary categories for assessing the quality of the concept map developed by students. Some of the common solutions proposed by students included the construction of modular buildings using recycled steel, prefabricated green concrete structures, and a bamboo-based building designed for disassembly, among others. Some concept maps reflected the students' conceptual understanding of the topic with few or no misconceptions. Additionally, students also showed both simple and complex relationships in the concept maps with a clear indication of relative importance. Overall, most of the participating students developed a more holistic concept map for addressing the construction and demolition waste issues by considering design for disassembly and upcycling principles as well as disaster management guidelines to improve sustainability in construction. Then, through the identification of different relationships and patterns among the concepts, students were able to clearly articulate the impact of these systems on the circular economy. Each student group presented their concept map within 3 minutes presentation to receive feedback on how they performed. Moreover, 11 out of 15 student groups performed well in the presentation by clearly showing their systems thinking ability to generate practical solutions to different construction and demolition waste issues through circular economy strategies. To this end, construction projects are becoming very complex, and it is critical to teach such combination learning modules among construction management students about the circular economy approach to achieve sustainability in the construction industry.

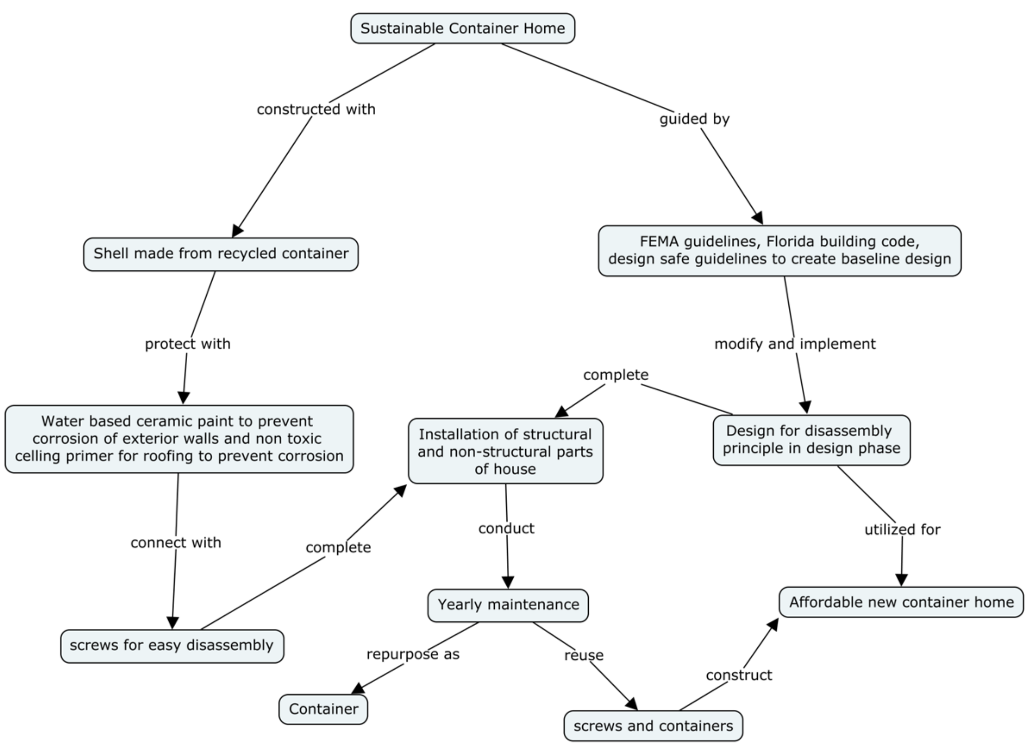

Figure 3. Non-linearly organized sample concept map developed by a student group for addressing construction and demolition waste issues in the construction industry.

Quantitative Results for Students' Skills

The study utilized the Wilcoxon Signed-Rank test to analyze the pre- and post-course survey data and evaluate the efficacy of the combination learning module. Students rated their current skill level and confidence to use those skills on a scale from 1 to 5 in the pre-survey. Then, after the completion of the combinational learning module activities, students reassessed these variables in the post-survey. As shown in Table 3, the statistical analysis results show that the observed difference between both measurements is significant which is indicated by a p-value less than 0.05. Additionally, Table 1 and Table 2 shows that there is an increase in mean values of students' rating in the post-course survey in comparison to the pre-survey. It can be inferred from the results that the combination learning module caused a significant increase in technical communication skills (i.e., talking with someone from within the course about the circular economy), Interdisciplinary communication skills (i.e., talking about technical details with someone from outside the course about the circular economy), systems thinking ability in the circular economy, provide feedback to team members about the circular economy, receive criticism from team members, and communicate technical information related to a circular economy to people within the field of expertise. Since 52 students reported that they have not learned or received any training on circular economy practices such as design for disassembly, deconstruction, and life-cycle assessment, etc. in the pre-survey, it can be inferred from the results that the combination learning module improved their knowledge about circular economy and soft skills. Although there were no specific questions that assessed students' ability to correctly define circular economy concepts or conduct life-cycle analysis, the combination learning module provided students with an opportunity to remember concepts, explain ideas, use information in real-world scenarios, draw connections among ideas, evaluate their ideas, and produce original solutions. The concept maps developed by students provided a profound understanding of their reflection and interpretation of the concepts related to circular economy and systems thinking. Furthermore, the improvement in students' systems thinking ability and ability to communicate is supported by an increase in mean and standard deviation of pre- and post-survey descriptive statistics results.

Table 1. Descriptive statistics for pre-course survey data

S.N.	Variable	Min	Max	Mean	Std Deviation	Variance
1.	Technical communication skills	1	5	2.19	1.04	1.09
2.	Interdisciplinary communication	1	5	2.06	1	1
3.	Systems thinking ability	1	5	2.14	0.97	0.93
4.	Providing feedback	1	5	2.34	1.28	1.63
5.	Receive criticism	1	5	3.25	1.43	2.03
6.	Confidence to communicate technical information	1	5	2.36	1.2	1.45

Table 2. Descriptive statistics for post-course survey data

S.N.	Variable	Min	Max	Mean	Std Deviation	Variance
1.	Technical communication skills	1	5	3.15	0.88	0.77
2.	Interdisciplinary communication	1	5	3.11	0.87	0.76
3.	Systems thinking ability	1	5	3.21	0.83	0.69
4.	Providing feedback	1	5	3.45	0.89	0.8
5.	Receive criticism	2	5	3.72	0.88	0.77
6.	Confidence to communicate technical information	2	5	3.55	0.76	0.58

Table 3. Wilcoxon signed-rank test statistics results for pre- and post-course survey data

S.N.	Variable	Z-value	Df	P-value
1.	Pre- and Post-Technical communication skills	-4.425	60	<0.001
2.	Pre- and Post-Interdisciplinary communication	-4.656	60	<0.001
3.	Pre- and Post-Systems thinking ability	-5.048	60	<0.001
4.	Pre- and Post-Providing Feedback	-4.672	60	<0.001
5.	Pre- and Post-Receive criticism	-1.909	60	0.05
6.	Pre- and Post-Confidence to communicate technical information	-5.020	60	<0.001

Students who participated in the combination learning module were asked to rate the scope of this method based on their experience in four different areas: (1) solve problems in other courses; (2) brainstorm ideas for real-world problems in their professional career; (3) educate peers about circular economy concepts such as deconstruction and design for disassembly; and (4) implement the circular economy principle in their professional career. Each student rated these areas on a scale of 1 (i.e., Definitely not) to 5 (i.e., Definitely). The obtained box plot results indicated that the proposed pedagogical approach positively influences all four areas, as indicated by the median value of 4 which is represented by the dark straight line in the box, as shown in Figure 3. Additionally, all four box plots have a maximum value of 5 which is represented by the top portion of the box. These findings indicate that many students were inclined towards learning about concepts of life-cycle analysis, circular economy, and sustainability as well as using the lessons learned from the combination learning module in their academic and professional careers.

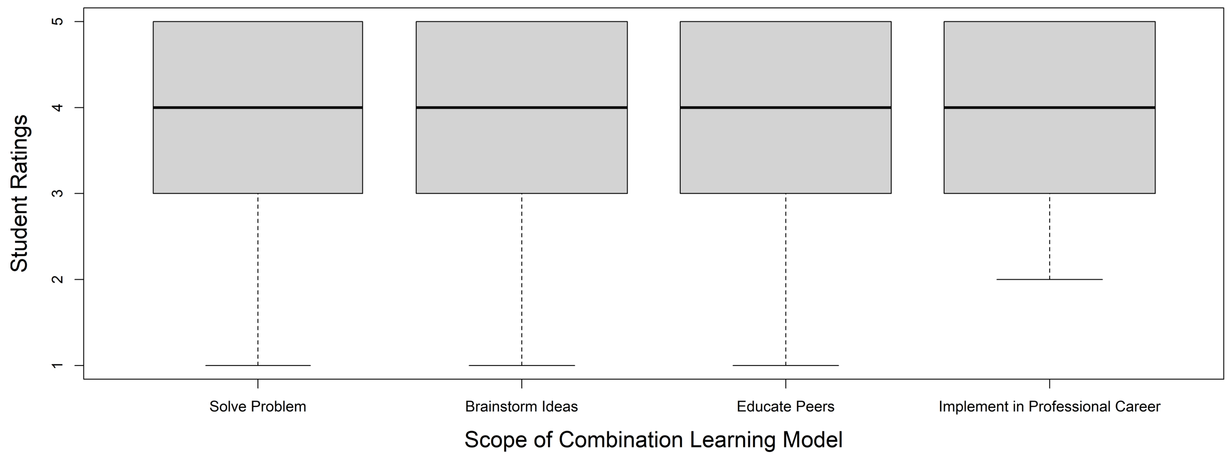

Figure 3. Box plots showing the scope of the combination learning model based on student perception, n=61

Qualitative Results

The study also recorded qualitative data concerned with students' perspectives on the efficacy of the combination learning module related to circular economy practices, as shown in Figure 4. The obtained data were categorized into three categories, including positive, negative, and impartial feedback. There was no resistance among students to learning and implementing the concepts related to LCA, circular economy, and sustainability in general since it hasn't been integrated into any of the previous courses within the university. Overall, approximately 90% of the feedback was positive such as:

- *What I enjoyed the most was working within a group allowed all of us to express our ideas. This generated a better concept map and solution for the problem in my opinion.*
- *It improved my critical thinking and social skills.*
- *It was very instructive and learned about different sustainable materials that can be used in a built environment to promote a circular economy.*
- *It helps me visualize the circular economy process better.*
- *Sparked creativity to think about ways to use sustainable practices every day on the construction site.*
- *It helped to break down the problem into different interconnecting steps to analyze it effectively with consideration of LEED criteria.*
- *It is an interactive way to learn and implement concepts.*
- *Made us think outside the box.*

However, there was also one negative feedback such as:

- *I did not like it. It doesn't seem to be useful.*

Additionally, there were a few impartial feedback such as:

- *It is something different I have never done.*
- *The fact that we got to apply the concepts to a real-world problem.*

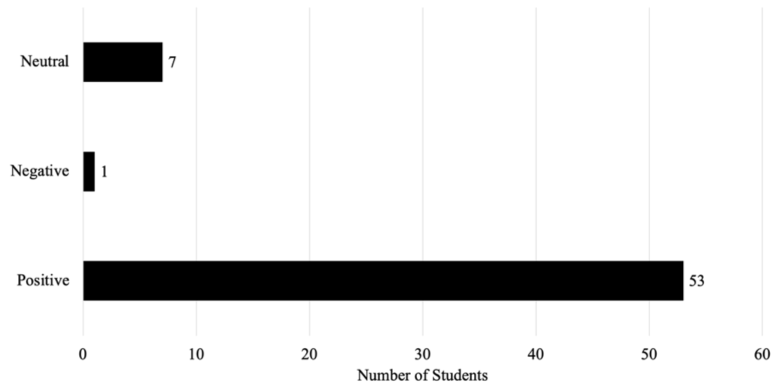

Figure 4. Students' qualitative feedback on the efficacy of the combination learning module, n=61

Limitation and Future Work

One of the study's limitations is that the research has been conducted in a Minority serving institution indicating that 90% of the sample size in the study includes a minority population. Therefore, future studies could focus on investigating the research in several institutions with a diverse student population from different socio-demographic backgrounds. The research also acknowledges the subjective nature of the survey responses due to personal opinions and self-judgments. However, the authors believe that correlating the survey questions to relevant literature supports valid conclusions and judgments. Moreover, students may be more favorable to an intervention in a short-term study. To understand the impact of a combination learning module for learning circular economy, a similar module needs to be continued over the years to understand the long-term impact on student engagement.

Conclusion

Circular economy education teaches students about their environmental responsibility as an engineer or architects to promote resource conservation and minimize waste. However, circular economy involves complex concepts which could be difficult to understand and visualize for many students. Since the Architectural, Engineering, and Construction industry is increasingly moving towards a circular economy approach, understanding the concepts of design for disassembly, upcycling, life-cycle analysis, and deconstruction is becoming a critical skill set for graduating engineers and architect students. This study addressed these challenges through the integration of a combination learning module that not only focused on helping students gain technical knowledge but also professional skills and metacognitive skills. The problem-based learning and concept map development activity helped students to think critically about the problem and clearly articulate the implications of their circular economy solutions. Student's improvement in their skills is supported by the Wilcoxon Signed-Rank statistical analysis which showed students made progress in the post-survey in comparison to pre-survey data. The obtained qualitative data was also significantly positive, and many students reported that the pedagogical approach was an interactive way of learning and visualizing concepts. The findings of the study contribute to sustainable construction and engineering education bodies of knowledge by preparing the future workforce with the necessary skills and knowledge to meet the challenges of building in a sustainable, economical, and responsible way.

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